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MASSIVE STARS IN THE CENTRAL PARSEC OF THE GALAXY

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Abstract. The central parsec of our Galaxy harbors a cluster of young massive stars orbiting the supermassive black hole SgrA*. We present a detailed analysis of these stars, focusing on their stellar and wind properties. We show that they are similar to other Galactic stars, pointing to no particularly special evolution in spite of the hostile environment. We are able to identify a clear evolutionary sequence between Ofpe/WN9, WN8, WN/C and LBV stars. The population of Wolf-Rayet and OB stars fully accounts for the ionizing radiation necessary to produce the observed nebular emission.

1 Introduction

With the progress of infrared observations, the center of our Galaxy reveals little by little its secrets. In particular, the stellar components of the massive cluster surrounding the supermassive black hole SgrA* are unraveled as spectro-photometric information are gathered by present day large telescopes. Since the first discovery of bright stars with H and He emission lines by Forrest et al. (1987), the number of spectroscopically identified stars in this cluster has widely increased. It turns out that a significant number of these stars are young, massive objects. This is puzzling: how can such objects be present so close to the black hole and its strong tidal forces? This question is referred as the "paradox of youth" of the Galactic Center. Understanding the origin of these massive stars is thus a key question, not only for the Galactic Center, but also for the broader field of Active Galactic Nuclei.

In this context, we present here a detailed analysis of the massive stars in the central parsec of the Galaxy.

2 The central cluster

The first observations of the central cluster of our Galaxy revealed ∼ 10 very bright stars (Forrest et al. 1987, Allen et al. 1990). Strong emission lines from H and He I were present in their K-band spectra, so that they were immediately nicknamed "He I" stars. At that time, such stars had never been observed elsewhere. Analysis of their spectra with atmosphere models soon showed that they were in fact cool, evolved massive stars (Najarro et al. 1994, 1997), which was confirmed by infrared observation of Luminous Blue Variables (LBVs) and related objects, showing similar K-band spectra.

In the last years, tremendous progress in infrared observational techniques have led to the discovery of a much larger population of massive stars. This is especially due to the development of 3D spectroscopy, a new powerful tool to study stellar clusters. Recently, SINFONI on the VLT was used to actively observe the Galactic Center: not less than 100 massive stars have immediately been identified (Paumard et al. 2006). Among them, we count ∼ 30 Wolf-Rayet and evolved stars, as well as several tens of OB stars, including supergiants but also main sequence objects. The detailed study of this population shows that it results from a burst of star formation ∼ 6 Myr ago. Combining radial velocities from spectroscopy and proper motions from imaging observations, Paumard et al. (2006) have shown that these stars gather in two separate and counter-rotating disks. This is, among other facts listed by Paumard et al., a clear indication that this population of massive stars was formed in one or two self-gravitating disk(s) able to survive the tidal forces of the supermassive black hole. But is star formation in such a disk similar to star formation in less extreme environment? Part of the answer requires a quantitative knowledge of the properties of these massive stars.

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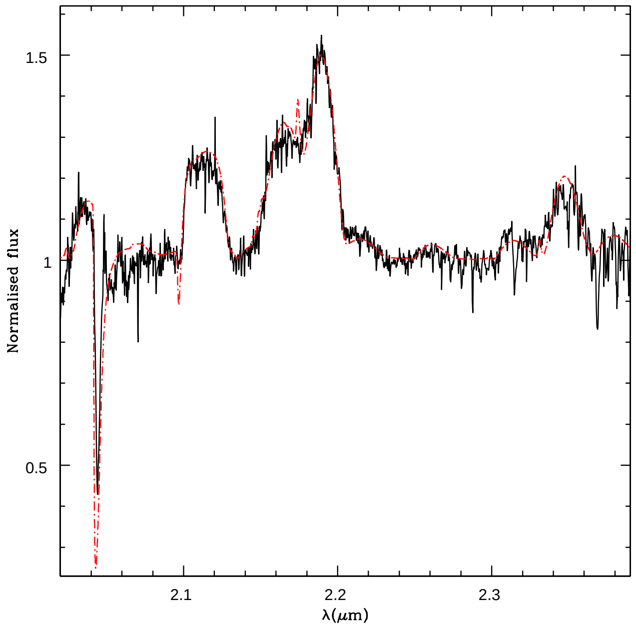

Fig. 1. Best fit (red dot-dashed line) of the observed (black solid line) K band spectrum of the WN5/6 star IRS16SE2.

3 Quantitative analysis of Wolf-Rayet stars and related objects

We have used the atmosphere code CMFGEN (Hillier & Miller 1998) to compute non-LTE models including winds and line-blanketing. Such models have been used to quantitatively analyze SINFONI K band spectra of most of the evolved massive stars of the central parsec. In Fig. 1, we show an example of such a fit. The main parameters we could derive are: effective temperature, luminosity, mass loss rate, surface abundances and wind terminal velocity.

The main result of this analysis is that the properties of the GC evolved massive stars do not differ from other Galactic stars. This is an indication that their star formation and evolution in the GC is not too much affected by the presence of the black hole.

4 Stellar evolution

To quantify a little more the evolution of these massive stars, we have focused on the following type of stars: WN8, WN/C and Ofpe/WN9 stars. The He I stars first discovered in the GC are now classified as Ofpe/WN9. Such objects are actually related to LBVs (e.g. Trippe et al. 2006). WN/C stars are Wolf-Rayet stars showing both CNO and He burning products at their surface (namely N and C). They are a rare class of WN stars on their way to the WC phase. Finally, WN8 stars is known to be the category of Wolf-Rayet stars being the most variable

From the quantitative analysis of several of these objects, we are able to identify the following evolutionary sequence:

$$\text{(LBV)} \rightarrow \text{Ofpe/WN9} \rightarrow \text{(LBV)} \rightarrow \text{WN8} \rightarrow \text{WN/C} \rightarrow \text{WC9}$$

Indeed, stellar abundances reveal that Ofpe/WN9 stars are the less evolved, while WN/C and WC9 stars are the closest to the supernova phase. Fig. 2 shows quantitatively that WN/C stars are in an intermediate evolutionary state between WN and WC stars. The above scenario, which we think is valid for stars with initial masses in the range 25-60 $M_{\odot}$, also fully accounts for the evolution of effective temperatures and luminosities in the different phases.

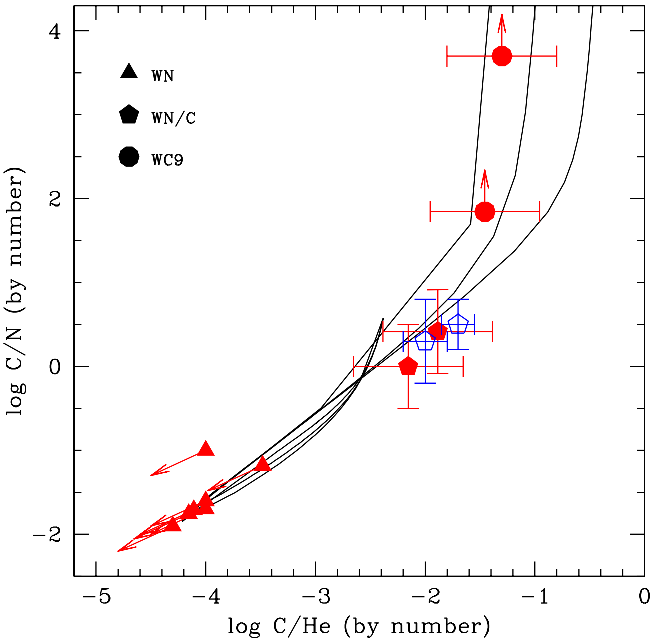

Fig. 2. Number fraction of C/N as a function of C/He for WN8 (triangles), WN/C (pentagons) and WC9 stars (circles). The open symbols are stars from Crowther et al. (1995). The black solid lines are Geneva evolutionary tracks. Arrows indicate upper/lower limits. N is produced in WN stars, and destroyed in WC stars. For C, it is the opposite. We see that quantitatively, WN/C stars are in an intermediate state of evolution between WN and WC stars.

5 IRS16SW: a massive eclipsing binary

The determination of masses of the hottest stars is usually a difficult task, unless they are in a binary system. In the GC, we have conducted a spectro-photometric monitoring of the He I stars and showed that one of them, IRS16SW, was indeed a multiple system. Both its light-curve and its radial velocity curve (see Fig. 3) show clear signatures of an eclipsing binary. Performing an orbital solution, we could show that both components have a mass of the order 50 $M_\odot$. This result is especially interesting since IRS16SW is an LBV candidate and the LBV phenomenon is still poorly understood. In particular, it is not clear which stars will experience such a phase during their evolution. Here, we have the example of a star with a initial mass in excess of 50 $M_\odot$ which is closely related to a LBV. This is a strong constraint for stellar evolution models.

6 Ionizing properties

An important property of the central cluster is its ionizing radiation. Indeed, previous studies have shown that the ∼ 10 He I stars were able to account for the H ionizing photons necessary to produce the nebular emission, but were much to cool to account for the He I ionizing radiation. With our new atmosphere models and the new population of massive stars (especially hot Wolf-Rayet stars and OB stars), this is not the case any more: the known population of GC massive stars can perfectly produce the ionizing photons at all wavelengths to ionize the gas and generate the observed nebular emission.

This is an important result since it shows that standard stellar evolution does not fail to explain the GC population. Indeed, Lutz (1999) computed population synthesis models using standard evolutionary tracks to reproduce the observed GC population. From such a model, he showed that most of the ionizing power should come from a region around the main sequence, while observationally all the ionizing flux was produced by the cool, He I stars. Lutz (1999) concluded that the evolutionary tracks used in the population synthesis models did not spend enough time in the cool part of the HR diagram. With our new results, this conclusion is not valid anymore: we find that most of the ionizing photons are due to OB and hot Wolf-Rayet stars, as predicted

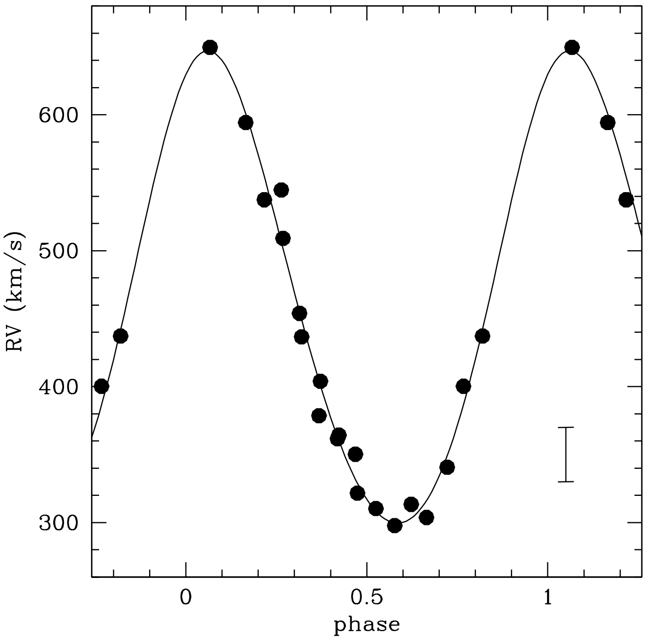

Fig. 3. Radial velocity of IRS16SW together with the best fit model (solid line). The period is 19.45 days. A mass of ~ 50 M$_{\odot}$ is derived for each component.

by the population synthesis model.

7 Conclusion

We have performed a quantitative analysis of the stellar and wind properties of the massive stars in the central parsec of the Galaxy. These stars appear to be normal massive stars, following a standard evolution. They account for the ionizing property of the central H II region. One of them is a binary composed of two ~ 50 M$_{\odot}$ stars.

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